Final Technical Report

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1. Abstract

This award is a one-year supplement to support the significantly expanded Alaska operations. In recent years, ANSS support to the Alaska Earthquake Center has evolved into two tranches: our five-year cooperative agreement that supports data analysis, and single supplements (including this one) that support field operations, acquisition and dissemination, and partial product support.

The proposal that led to this award outlined four tasks. Activities and success measures for these tasks are provided in the sections that follow.

2. Task: Partner Coordination

National Tsunami Warning Center: We continue dedicated and redundant real-time waveform exchange to the benefit of both parties. We reach out to NTWC following potentially tsunamigenic earthquakes—including this year the July 22 M7.8 and October 19 M7.6 Simeonof earthquakes—to ensure that our messaging on potential tsunami effects is consistent.

Alaska Volcano Observatory: We receive real-time waveform data from about 200 AVO stations that expand our network coverage in the Aleutians. In exchange, we provide AVO with regional AK data from stations located in close proximity to their areas of interest. To support these efforts AEC maintains dedicated server hardware near USGS volcano facilities in Anchorage. When possible, we coordinate field maintenance efforts for co-located sites. We were not able to do so in 2020 due to COVID-19 restrictions.

EarthScope Transportable Array: We continue to integrate the remaining TA stations located in Alaska and Canada into our real-time and off-line data processing (about 85 sites). The lifespan of the remaining TA stations in Alaska has been extended for another year with the removal now targeted for the summer of 2021, also due to COVID-19 considerations. We continue acquisition and distribution of recently acquired TA stations through IRIS DMC archives, ensuring full inclusion in ANSS waveform and derived products.

Canadian Seismic Network: We continue real-time waveform exchange with our Canadian neighbors by importing data from about 30 sites located in western Canada. This data augments our coverage of the astern Denali fault and south-east Alaska. The Canadian Seismic Network operators have full access to Alaska data through our SeedLink server.

National Strong Motion Project: We continue to make available all AK strong motion data to the NSMP via in-house seed-link and also via IRIS DMC archive. In 2020 we made 11 stations that are part of the Trans-Alaska Oil Pipeline earthquake monitoring system publicly available. We continue to acquire and distribute data from urban strong motion networks in Fairbanks (about 10 sites) and Anchorage (about 35 sites). We import real-time NP network data from about 20 sites into our waveform archive to be used for earthquake detection and ShakeMap generation purposes. These include triggered data from NetQuake sites located in Anchorage and the Mat-Su Borough, and continuous data streams from instruments located in Kodiak, Seward, and Sitka. We also coordinated field maintenance of the Anchorage SM network, which was complicated by COVID-19 travel restrictions this past year.

ANSS: We continue to coordinate our response to significant earthquakes with coordinating scientists at NEIC, such as during the July 22 M7.8 and October 19 M7.6 Simeonof earthquakes. While both earthquakes were located outside of the AK authoritative region, our coordination ensured consistent magnitude reporting and product generation.

New partners: During this award, the center entered new third-party agreements with the Missile Defense Agency, Donlin Gold Mine, and the Alaska Gasline Development Corporation. The agreements led to two new broadband/strong motion sites, an additional USArray adoption, and a new strong-motion-only site in Cook Inlet. Though these developments are external to our USGS awards, we pursue the data using the same ANSS standards. We successfully negotiated open data policies for all of these awards. The data are being distributed as part of the AK network and are being fully integrated into ANSS products including the hypocenters and ShakeMap.

3. Task: Field Operations

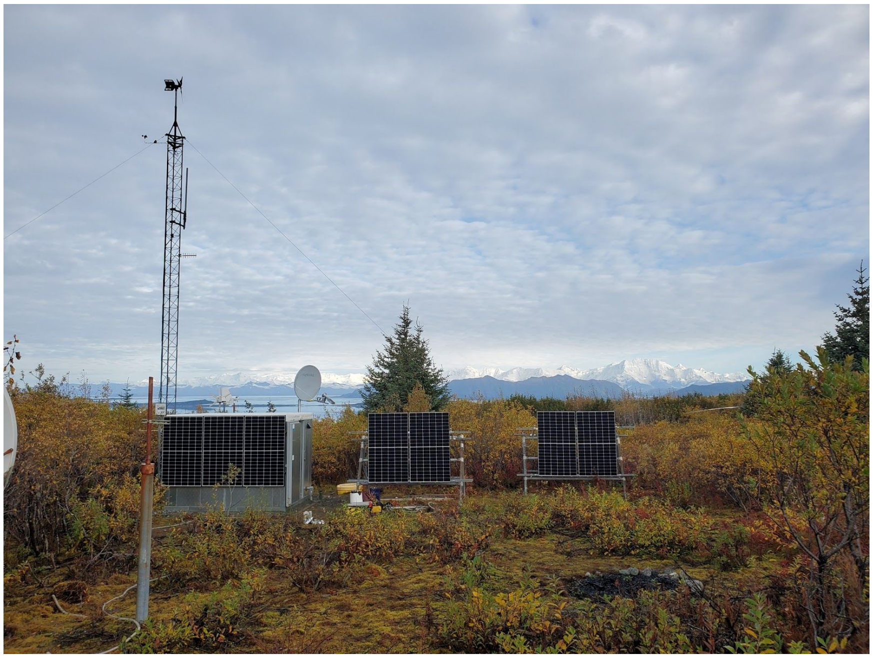
Our plans for fieldwork in 2020 included a major renovation of a communication hub serving 11 stations, an expansion of the strong-motion footprint, replacements of malfunctioning or damaged sensors, and other routine maintenance. Facing pandemic-related travel restrictions starting in March and throughout the field season, we cut all work from our plans that required travel to remote villages off the road system. These cuts affected planned work at 14 sites. We reorganized our plans to focus on sites that we could reach with minimal interpersonal contact. Between May and November, AEC personnel spent 194 person-days in the field and made 123 visits to 72 different sites to perform maintenance.

Technician Evan Mcarthur showing the clean up of a long-abandoned seismic station originally installed in 1976 in the Wrangell-St. Elias region. Clean up of these jointly-operated sites is an on-going "as feasible" effort.

In line with expanding our strong motion coverage within the network, we installed new strong-motion instruments at five existing sites and replaced four other strong-motion instruments that were aging or malfunctioning. We installed two new strong-motion stations in Eagle River. This effort was coordinated with the engineering community in Anchorage, NSMP, and University of Alaska Anchorage.

New strong motion sites in Eagle River. This area, northwest of central Anchorage, was the site of some of the worst damage during the 2018 M7.1 earthquake. Ground motion predictions and DYFI reports remain ambiguous as to whether or not this region actually experienced stronger shaking, or whether the damage is better attributed to building standards. At the time of the earthquake, no instrumental data was available in Eagle River. These new sites are a step in addressing the issue.

We replaced two malfunctioning broadband instruments. We worked to resolve 15 data outages and made telemetry changes aimed at reducing latencies and improving reliability. These telemetry changes took the form of antenna upgrades, internet service provider changes, and other equipment upgrades. At a few sites with weak cellular service, we replaced cellular modems with UHF radio links.



The upgraded receive facility at Bering Glacier Camp. This remotely-powered site aggregates radio channels from the southern Wrangell-St. Elias region and forwards them via a VSAT satellite uplink.

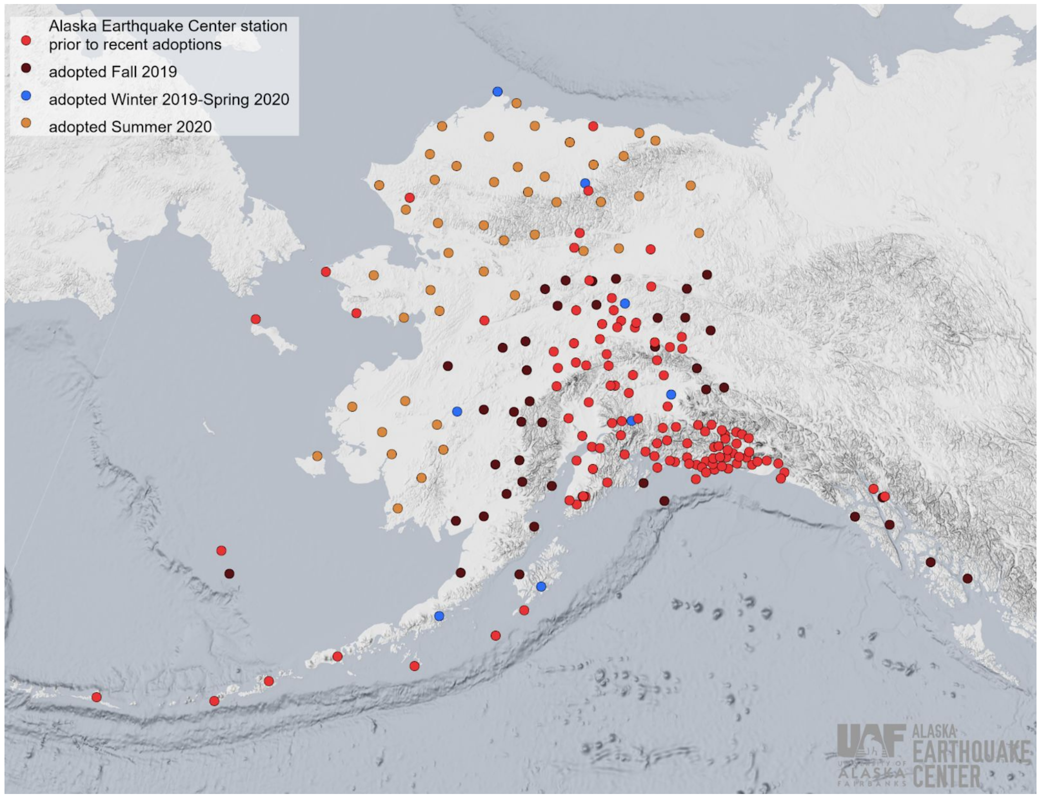
At Bering Glacier Camp, a communication hub on the coast of the Gulf of Alaska that serves as a repeater for data from 11 stations, we replaced the equipment enclosure, solar array, battery system, and satellite communication system. This major renovation was aimed at improving the reliability of a power-hungry site where outages have an asymmetrical effect on our data return percentage. We also replaced batteries at six other sites with more conventional power systems and installed new solar arrays at four sites.

4. Task: Data Acquisition and Management

5.1 Finalizing USArray station acquisitions

During 2019-2020, the Earthquake Center underwent an unprecedented expansion of our permanent seismic monitoring network. In total we acquired 96 of the 158 temporary USArray sites in Alaska. The adoption process began in the fall of 2019 with 43 sites located in Southcentral and Southeast Alaska. After this initial adoption, eight more sites were added in the winter of 2019 and spring of 2020. Four of these sites were co-located with larger geophysical observatories and were given to us free of charge to enhance the existing facilities. The final 45 sites, located across the northern and western portions of the state, formally transitioned over this past summer through the program affiliated with the National Science Foundation Arctic Observing Network Program. Though funded under non-USGS support, we are archiving and disseminating these data guided by ANSS expectations. Overall, this effort greatly expanded the footprint of the AK network by adding about 60% more stations, the majority of which are in areas that previously suffered from poor network coverage.

Map showing the three phases of USArray adoption between Aug. 2019 and Sept. 2020



<u>5.2 Hardware upgrades</u>

During the summer of 2020, AEC embarked on upgrading our server hardware. Our existing computer cluster, which contained three servers and two storage area-network (SAN) devices, had been in operation for half a dozen years and was approaching end-of-life for vendor support. This cluster supported nearly all critical monitoring systems, including our data acquisition and archival, real-time event detection, alarming, ShakeMap, data exports, and web hosting, plus it hosted numerous development and testing systems.

We worked closely with Dell computers to design a new system that would meet the center's projected compute needs for the next five years. A major point we wanted to address for continuity of operations was the reliance on the two non-redundant SAN devices for data storage. While these devices had redundancy at the hard disk level (operating with RAID 6), the cluster could not sustain the loss of an entire device without going offline.

We purchased four Dell R740xd PowerEdge servers for the new cluster. Each node provides 24 CPUs with 64.8 GHz total clock speed and 256 GB of RAM, for a total cluster of 96 cores operating at 259 GHz and 1024 GB of RAM. This represents an increase of 3x in CPU capacity from our old system and a 2x increase in RAM.

To address storage, we opted for a newer technology from VMWare called vSAN. This technology allows for storage to be abstracted, much like how compute resources are abstracted in the normal VMWare system (for example, how a single node can host dozens of virtual machines). Under this architecture, each of our nodes have approximately 13 TB of extremely high performance flash NAND storage, which are pooled into a (usable) cluster capacity of 37 TB operating at a much higher performance level than our old spinning drive arrays.

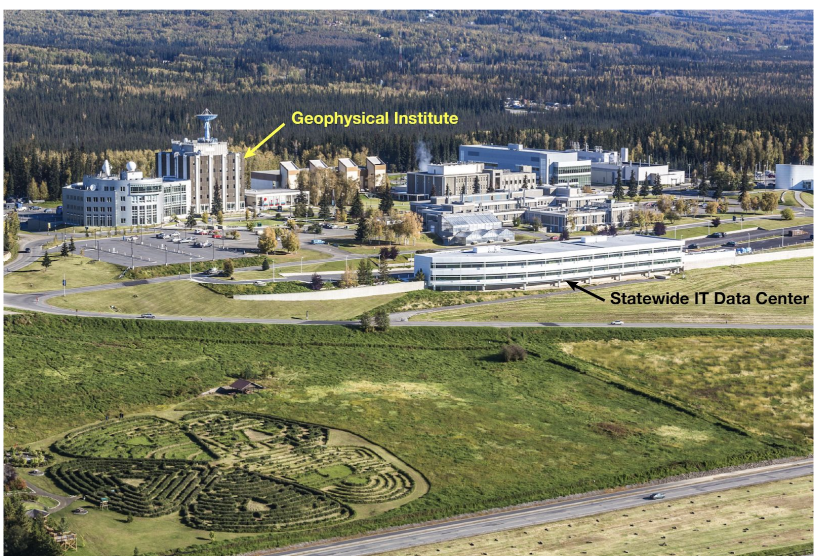
To supplement the vSAN storage, we also purchased two Synology RS4017xs+ rack-mounted network attached storage (NAS) devices, each with approximately 190 TB of usable storage capacity. These have been deployed in a redundant setup, whereby the data on one is directly mirrored to the other. These devices provide long-term storage of our waveform archive, as well as backups of production virtual machines.

5.3. Cybersecurity

We have taken numerous steps to increase our network cybersecurity during this award. All cell modems at remote sites have been moved off of public IP addresses and onto private networks, dramatically decreasing their exposure to threats from the outside world. We have continued to update the configurations of our field routers to match best practices, including disallowing any outside services (such as ICMP or SSH) from networks outside of our lab. Finally, we continually check to ensure that all devices' firmware is current and all applicable OS and software patches are applied on field devices as well as in the lab.

5.4 Continuity of operations

To address continuity of operations during this award, we pushed to eliminate single points of failure in our computing cluster. By migrating from non-redundant SAN devices onto a distributed vSAN storage solution, we have eliminated potential downtime from a single device failure. Our current cluster can sustain the loss of an entire node without impacting our ability to perform earthquake monitoring. This redundancy has the added benefit of allowing us to perform nearly all preventative maintenance without downtime.



AEC is located within the Geophysical Institute. Several years ago however we moved all of our real-time systems into the enterprise-grade State IT Data Center. This is the facility transitioning to full diesel backup.

Additionally, during this award the university Statewide IT Data Center continued the process of adding a backup diesel generator to power critical data operations, including those of the center. Within the university, AEC has been the poster child for this effort from the start. We are very pleased to see the university take these efforts on our behalf (and on university funds). We are somewhat disappointed in the speed of the project. This backup power was supposed to be fully in place by mid-2020. Technical issues have now pushed this into 2021. The full install has not been completed yet, but the power systems of the building have been modified to allow for the generator to be installed inline. Once operational, our servers will be able to sustain roughly three days of operation in the event of a primary power failure, a notable improvement over the 30 minutes of backup power that is currently available via uninterruptible power supply.

We have continued to explore using Cloud-based services to augment our local systems. A major success we had was to establish an encrypted GRE connection between our university network and our private network in Amazon Web Services. We then enabled remote access to the AWS network via VPN, and enabled routing such that staff can connect to the Amazon-based VPN and securely access services and systems inside the AEC internal private network. This connection acts redundantly with the university-maintained VPN service, allowing for backup access to our critical systems.

5. Task: Products and Dissemination

6.1 Web server capacity

Under this award, our goal was to increase the capacity of our website in order to better handle the amount of traffic that we receive immediately after widely felt earthquakes. We identified that the primary source of problems was related to SSL termination on our website front-end for traffic arriving via HTTPS. The termination program, *pound*, was reliant on the filesystem for opening and closing the connections. Attempts to address the problem at the software level met with modest success. Because our web server was running on a networked system of spinning drives, this put a very real physical cap on the ability of the web site to handle large amounts of traffic. Based on observations in the later part of 2020, the upgrade of our production computing cluster to solid state devices made notable improvements to the capacity of our public web server to handle short-lived spikes in web traffic. We acknowledge that adding additional load-balancing capacity, either via local virtual machines or through a cloud-based mechanism, is the long-term solution to the problem and are planning on going forward with this.

6.2 Transition from Google Maps

When the center's modernized website went live in 2015, much of our interface was based around an interactive map using the Google Maps framework. However, that framework proved problematic, especially when Google changed their pricing structure making the center's continued use unsustainable long-term. Therefore, we made transitioning our website away from Google Maps a priority for us.

We put substantial effort into the transition under this award. We rewrote the full mapping backend, utilizing Leaflet as the application programming interface (API), and Mapbox as the tile server. Both were chosen for their relative maturity, vendor support, and widespread adoption within the marketplace. The codebase is entirely Javascript and widely used libraries, ensuring that we can control when and how features are added or changed, a recurring problem we had with Google Maps. We also were able to ensure that the map was designed from the beginning to be easy to use and fully functional on mobile devices, which represent approximately 70% of our website user traffic.

6.3 ShakeMap 4

We undertook testing to ensure smooth transition to ShakeMap version 4 under this award. We have an installation in place for testing and ran select events to investigate how to integrate the new software into our operational workflow. During testing, we identified the need to ensure the concurrent updates of our data products, especially between adding and updating earthquakes on our website, ShakeMap, and posting solutions to Comcat. We added this capability as a primary goal of a development project launched late in 2020, and opted to pause deploying ShakeMap 4 until we finalized this synchronization mechanism to avoid having to refactor the code linking the center's data production environment to that of ShakeMap.

6.4 Social Media presence

During the reporting period we gained 6,000 new social media followers across two platforms, Facebook and Twitter, bringing our total followers to 37,000. We've maintained a vibrant and engaged social media audience with 89,000 engagements over approximately 600 posts. To maintain and increase engagement this year we diversified our content and added *#FieldworkFriday* and weekly seismicity reports to our regular posting. While reviewed event posts remained 50% of our posts, the remaining 50% of our content was spread between new original content (10%), field work (6%), seismicity reports (15%), general interest content (8%) and in-depth content pertaining to the M7.8 Simeonof earthquake and its aftershocks (11%). Our budding YouTube presence received a notable boost in January 2020 with the time-lapse video showing 2019 seismicity. The video was viewed by 9,000 people. Animations including landslide generation and the tectonic setting of the M7.1 Anchorage earthquake had 6,000 views.

6. Project data

Seismic data generated under this award is archived at and available from IRIS Data Management Center (http://ds.iris.edu/ds/nodes/dmc/data/). ShakeMap products and data are archived and available via ANSS Comcat (https://earthquake.usgs.gov/earthquakes/search/) and the AEC website (http://earthquake.alaska.edu/earthquakes/shakemaps/list). Seismic data is made available to USGS via dedicated seed-link export data server.

7. Bibliography

This award does not support research activities.

8. Measures of Success

Task: Partner Coordination

From proposal: The success of this task will be measured by the health and degree of interaction with the USGS Earthquake Hazards Program, and with each of the partner organizations listed above. The success of internal coordination will be measured by demonstrating the timely execution of tasks and the effective use of resources. We strongly suggest that the USGS Earthquake Hazards Program consider a site visit to the AEC during the lifespan of the award to understand how this coordination manifests day-to-day.

This year's activities included the largest and third-largest earthquake in the world. Our interactions with NEIC during this time were smooth and absent issues we have seen at times in the past. The tasks described throughout this award were generally achieved, as proposed, with minor deviance. Specific examples of external partner coordination are elaborated in section 3, page 3. A virtual site visit was conducted by USGS in late 2020. This was a positive experience. We encourage continued site visits and look forward to a time when they can be conducted in person.

Task: Field Operations

From proposal: The success of this task will be measured by:

<u>+ number of sites inspected, maintained, and repaired</u>

Despite covid complications, we were able to inspect and/or repair 72 sites. Some of these required return visits for a total of 123 site-visits during the 2020 season. Details in section 4, page 3.

<u>+ number of old sensors and dataloggers replaced</u>

Six seismometers were replaced with newer models. We swapped a half dozen dataloggers to younger (but not new) models. To begin addressing the question of long-term datalogger upgrades across the network we acquired two different models to field test. We acquired three Quanterra Q8s which we are currently testing in-house. We also acquired two Nanometrics Cascadias which use the Centaur datalogger. These are deployed in the field.

<u>+ number of free field AK-network sites with strong-motion channels</u>

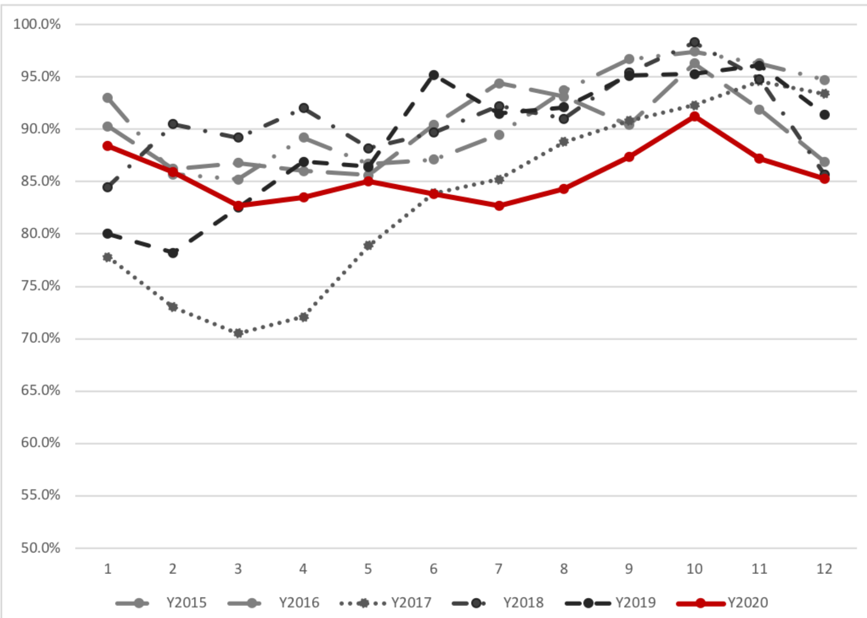
The total number of free-field AK-network sites grew by 15 this year. Section 4, page 3 includes strong-motion specifics for this award. The network benefitted from four new non-USGS strong-motion sites in this regard as well.

Task: Data Acquisition and Management

From proposal: The success of this task will be measured by:

+ station and network uptime

The figure below shows data availability for 20215 through 2020. Date return rates are on par, though on the low side, of recent years. To a limited extent, this reflects the covid-restricted field operations. However, the biggest driver is the expansion of the network. Not shown in this figure is the +60% growth in the number of AK-network stations contributing to these statistics--many on different power or communications links. We expect it will take multiple years for the completeness of the expanded network to match that of the pre-2019 small footprint network.



Data return rates from the AK-network 2015-2020.

+ availability of waveforms at the IRIS DMC and the Center for Strong Motion Engineering Data

For the first time, the IRIS DMC now contains 100% of the AK-network stations (see section 3, p. 3 for details). We consider this a major milestone. In addition, we have begun tracking systematically, the completeness of AK-network data at IRIS compared to our in-house holdings. There are at times discrepancies resulting from issues on either our end or theirs. Since we have begun tracking this during 2020, we have been able to eliminate or minimize some of these issues. Data completeness at IRIS has improved measurably.

Nine earthquakes appear in the CESMD database during this reporting period. That is larger than any prior year with the exception of 2018 which includes the aftershock sequence of the M7.1 Anchorage earthquake.

+ Demonstrated improvements in AEC's continuity of operations capabilities

Considerable efforts occurred on this topic including:

- Replacing server hardware with increased redundancy (section 5.2,. Page 6)
- Cybersecurity changes away from public IP addresses (section 5.3, page 6)

- Growth in cloud use, though hurdles remain on this topic (section 5.4, page 6)

Task: Products and Dissemination

From proposal: The success of this task will be measured by:

+ The effective implementation of ShakeMap v.4

ShakeMap 4 was installed and tested under this award. We are waiting on transitioning to operational use while we make changes to the underlying mechanism that triggers shakemap generation. This transition will occur early in 2021. See section 6.3, page 7 for details.

+ Increased load capacity of the AEC website

Upgrades to solid-state devices and changes in the web frontend made measurable improvements to load handling. This is described in section 6.1, page 7. Larger gains will require transition to cloud hosting. As discussed, these efforts are underway.

+ The discontinuation of Google-based map interfaces at earthquake.alaska.edu

We successfully transitioned away from Google-hosted map services during this award. Details are in section 6.2, page 7.

+ Wide disseminated of content that places ANSS products in an Alaska regional context

89,000 engagements over approximately 600 posts. More extensive details are in section 6.4, page 8.